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[1]S.T. Tuleukhanov, [2]O.I. Salatova, [1]Z.Zh. Zhanabayev, [1*]A.N. Oralbek, [3]Iu.A. Kim

[1]Laboratory of Human and Animal Physiology, Almaty, Kazakhstan
[2]A.Baitursynov Kostanay State University, Kostanay, Kazakhstan
[3]Institute of Cell Biophysics, Russian Academy of Sciences, Pushchino, Russia
[*]e-mail: aiko-22.03.1993@mail.ru

# Entropic index of diurnal dynamics of systolic and minute volumes of human blood before and after exercise stress

**Abstract:** The features of circadian dynamics of mean values of systolic and minute blood volumes of young people before and after the exercise stress have been recorded and analyzed. It is indicated that sizes of systolic and minute blood volumes after exercise stress increased with statistical significance of $p \leq 0.05$. Thus, the characteristics of systolic volume of human blood vary from 70.3±4.3 mL to 77.2±6.6 mL before exercise stress, and 92.6±8.8 mL up to 99.1 ±8.9 mL after the exercise stress. While for the minute volume, they vary from 5.00 ±0.50 L to 6.10 ±0.53 L and from 9.79 ±3.04 L to 11.19 ±2.53 L, correspondingly. The values of systolic volume of blood entropy before exercise stress are equal to 0.6208 and after exercise stress to 0.6438 and the value of minute volume of blood before exercise stress is equal to 0.6208 and after load is equal to 0.6438. The entropy characteristics of circadian dynamics with systolic and minute volumes of blood after the exercise stress has a tendency to increase. Despite numerous works on the study of percussive and minute cardiac output, there is yet no complete clarity about their relationship after the dosed physical exercises in the daily regime and nothing is known about their entropic parameters. Current work expounds the data on experimental material and the mathematical analysis on revealing the daily dynamics of systolic and minute volume of human blood before and after exercise stress and calculation of their entropic parameters.

**Key words:** circadian rhythms, systolic blood volume, minute blood volume, exercise stress, entropic parameters.

## Introduction

Current stage in the development of biomedicine is consistent in that along with the knowledge of the spatial organization of the living systems, their temporal organization is intensively studied [1-4].

Rhythmicity is the basic property of a living organism and its inherent quality as a symphony of rhythms and temporalities underpin our development. The analysis of chronobiologic regularities on the evolutionary level promotes a deeper study of the biological mechanisms of human adaptation and the purposeful application of effective means (eg. physical culture and sport) increasing the resistance of the organism to various stress factors [5, 6].

In life, there is nothing more powerful than rhythm. Indeed, information about the rhythm of physiological processes is necessary for rational work and rest (chronohygiene), for diagnosis (chronodiagnosis) and for the effective treatment (chronotherapy). Chronobiological data is used for the scientific substantiation of dosage of the medicinal products (chronopharmacology), organizing the rational sports training, increasing the human capacity and preventing premature aging [7-10]. Thus, optimization of the parameters of biological rhythms facilitates increasing the duration of human life.

In 2017, the Nobel Prize in Physiology or Medicine was given jointly to Jeffrey C. Hall, Michael Rosbash and Michael W. Young for their discoveries of molecular mechanisms controlling the circadian rhythm. As stated on the official page of the Nobel Prize (https://www.nobelprize.org/nobel_prizes/medicine/laureates/2017/press.html): "Using fruit flies as a model organism, this year's Nobel laureates isolated a gene that controls the normal daily biological rhythm. They showed that this gene encodes a protein that accumulates in the cell during the night, and is then degraded during the day. Subsequently, they identified additional protein components of this machinery, exposing the mechanism governing the self-sustaining clockwork inside the cell. We now recognize that biological clocks function by the same principles in cells of other multicellular organisms, including humans". In this connection, continuous scientific interest to chronobiology, chronophysiology and chronomedicine becomes clear. Regardless of a huge amount of work in these areas, there is still a large field of activity for new research steps.

## Materials and methods

$1^{st}$-$3^{rd}$ year bachelor students, 19-20 years old, 68±5 kg in body weight, male were used as objects of the study. All subjects for health reasons were assigned to the main group (physical activity 2 hours per week). Physical exercise was performed with the help of a cycle ergometer (Proteus Cycle Pec 3000, 2012 y., Proteus, Taiwan) in the Laboratory of Human and Animal Physiology, Department of Biophysics and Biomedicine, Al-Farabi Kazakh National University. The methodology for determining the minute volume of the heart and for processing the analyzed parameters was developed on a computer based on the physiological idiogram "The Physiology of the Circulation" programs were created for the "Pentium-4" (Intel company, USA) computer to determine the physical performance and the functional state of the circulatory system. To characterize the functional state of the circulatory system, the following indices were used, obtained experimentally: arterial pressure (systolic and diastolic, mm mercury column); heart rate (beat/min); body weight (kg); age (years). In addition, based on the above indices, such important parameters as minute blood volume (MBV, L/min) and systolic (stroke) blood volume (SBV, L/min) were calculated. Statistical processing of the obtained results was carried out with the help of the Microsoft Excel program and the changes were considered reliable at $p \leq 0.05$. The entropic index of the daily dynamics of MBV and SBV before and after the physical exercise was calculated using program MATLAB (Matrix Laboratory, USA) [11].

## Results and discussion

SBV is the volume of blood pumped from the left ventricle per beat. It is calculated using the measurements of ventricle volumes from an echocardiogram (ECG) and subtracting the volume of the blood in the ventricle at the end of a beat (called end-systolic volume) from the volume of blood just prior to the beat (called end-diastolic volume). The term stroke volume can apply to each of the two ventricles of the heart, although it usually refers to the left ventricle. The systolic volumes for each ventricle are generally equal, both being approximately 70 mL in a healthy 70-kg human. It is an important determinant of cardiac output, which is the product of systolic volume and heart rate, and is also used to calculate ejection fraction, which is systolic volume divided by end-diastolic volume. Because systolic volume increase in certain conditions and disease states, systolic volume itself correlates with cardiac function [12; 13].

Minute blood volume (MBV) and systolic or stroke blood volume (SBV) are the most important indicators of hemodynamics. With their help, it is possible to quantify the performance of the heart and its ability to increase the pump function with an increase in tissue metabolism leading to an increase in the oxygen demand of tissues. The values of cardiac output are also the basis for calculating a number of values that characterize the work of the heart and the entire circulatory system [14; 15]. For that reason, special attention should be given to these indicators.

Despite numerous works on the study of percussive and minute cardiac output, there is still no complete clarity about their relationship after the dosed physical exercise in the daily regime and nothing is known about their entropic parameters. Current work reflects the experimental material on daily dynamics of systolic and minute volume of blood of the person before and after the exercise stress and calculation of their entropic parameters (Table 1).

Judging by the averaged indices, SBV level before the exercise fluctuated by the type of a single-peak curve with a maximum at 8 pm and comparatively low values at the night (2 am).

SBV values in the norm during the day varied from 70.3 ±4.3 mL to 77.2 ±6.6 mL. The average SBV values after physical exercise during the day, both in rhythm configuration and in terms of SBV level, differed from the norm. While after the physical activity, the SBV values during the day varied from 92.6±8.8 mL to 99.1±8.9 mL, with a maximum at 4 pm and a minimum at 8 am. Averaged SBV indices before and after the physical exercise differ from each other both in level and in configuration of daily rhythms. SBV values after exercise are higher than in the norm.

The entropic parameters of SBV averaged values before and after the physical exercise are presented on Figures 1 and 2.

It can be seen from the Figure 1 that the values of the entropy of SBV in people before the physical exercise during the day vary from 70.5 to 77.3 mL and is equal to 0.6208 units.

**Table 1 –** Daily SBV dynamics before and after the exercise stress

| t, hour | 08 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 00 | 02 | 04 | 06 | 08 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BE | 77.2±6.6 | 76.4±6.9 | 74.3±5.6 | 74.9±6.0 | 75.3±3.7 | 75.0±3.7 | 74.8±3.9 | 74.6±4.0 | 74.1±3.5 | 70.3±4.3 | 71.1±4.4 | 75.5±4.2 | 76.5±4.5 |
| AE | 92.6±8.8 | 93.8±8.0 | 96.0±8.7 | 97.8±7.7 | 99.1±8.9 | 98.9±7.9 | 98.6±7.4 | 97.0±7.0 | 96.2±7.3 | 94.7±7.8 | 93.8±8.0 | 93.0±7.2 | 94.5±6.4 |

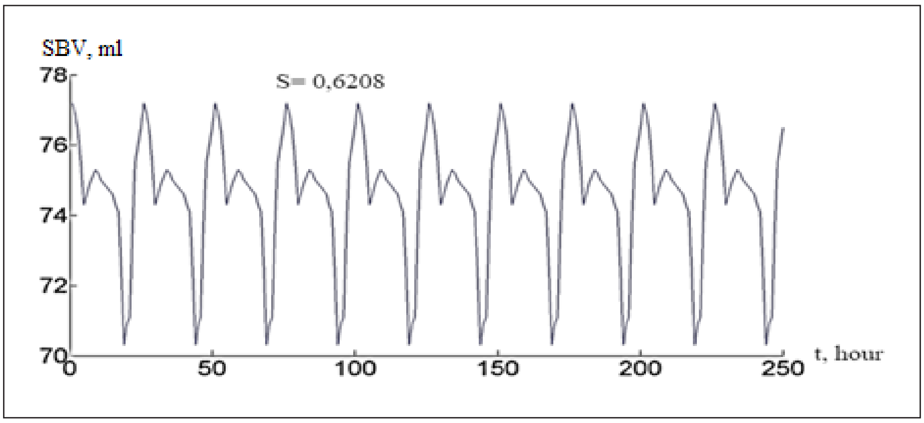


**Figure 1** – Entropic parameters of daily SBV dynamics before the exercise stress

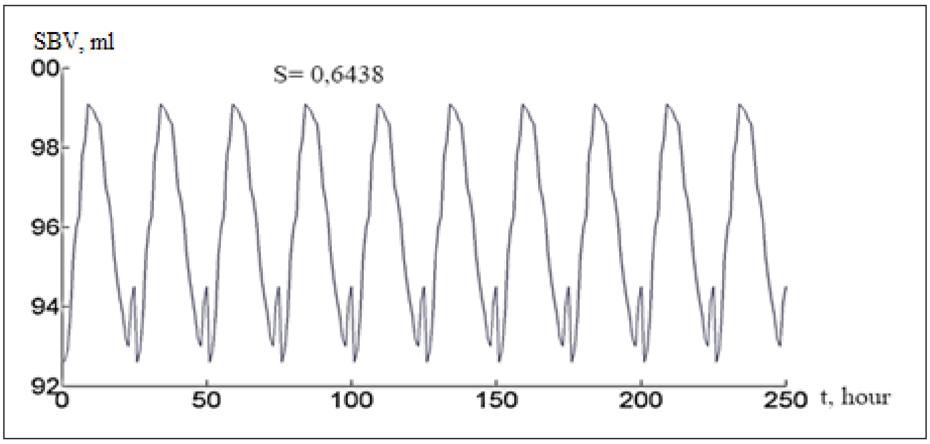


**Figure 2** – Entropic parameters of daily SBV dynamics after the exercise stress

The values of entropy of SBV after the physical exercise during the day varies from 92.5 to 99.4 mL, and is equal to 0.6438 units.

It is established that the values of the entropy of SBV before exercise are lower than after physical exercise. Thus, for the first time we calculated the values of the entropy of SBV in humans before and after physical exercise and found an increase in the value of entropy of SBV after the exercise, which indicates activation of the cardiovascular system of the human body.

Normal values for a resting healthy individual would be approximately 60-100 mL. Patients undergoing surgery or in critical illness situations may require higher than normal SBV and it may be more appropriate to aim for optimal rather than normal SBV.

Considering the daily chromodynamics of MBV average, it was found that it is a subject to fluctuations both before and after the physical exercise (Table 2).

Results show that MBV values before the exercise vary from 5.37 ±0.69 to 6.10 ±0.53 within a day, with a minimum at 4 am and with a maximum in 10 am, and after the exercise from 9.79 ±3.04 to 11.19 ±2.53, with a maximum at 4 pm and a minimum of 4 am.

**Table 2 –** Daily dynamics of MBV mean values in students before and after the exercise stress

| t, hour | 08 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 00 | 02 | 04 | 06 | 08 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BE | 6.09 ± 0.49 | 6.10 ± 0.53 | 5.92 ± 0.71 | 5.77 ± 0.65 | 6.05 ± 0.54 | 6.07 ± 0.57 | 6.04 ± 0.43 | 5.89 ± 0.55 | 5.72 ± 0.68 | 5.55 ± 0.70 | 5.37 ± 0.69 | 5.90 ± 0.52 | 6.02 ± 0.56 |
| AE | 10.06 ± 3.23 | 10.17 ± 3.01 | 10.87 ± 2.7 | 10.01 ± 2.44 | 11.19 ± 2.53 | 11.03 ± 3.03 | 10.99 ± 2.98 | 9.97 ± 2.04 | 10.64 ± 3.33 | 9.92 ± 2.09 | 9.79 ± 3.04 | 10.22 ± 3.07 | 10.50 ± 3.08 |

Studies of MBV daily rhythm before and after the physical exercise show that daily MBV values after the exercise are higher than before PE, by almost 81%. Thus, we have established the values of daily dynamics of MBV in youngsters before and after the physical exercise. The results for the entropy of MBV daily dynamics calculation before and after the exercise are presented on Figures 3 and 4. The results show that MBV curves normally vary from 5.37 L to 6.1 L during the day and are clearly organized in time and the entropy values are 0.6208 (Figure 3).

Increase in minute blood volume after exercise stress is caused by the increasing need of an organism for oxygen. It can be seen that the daily MBV rhythm after the exercise varies from 9.8 L to 11.2 L and is clearly organized in time, however, the rhythm frequency is denser than normal and the entropy index is 0.6438 (Figure 4).

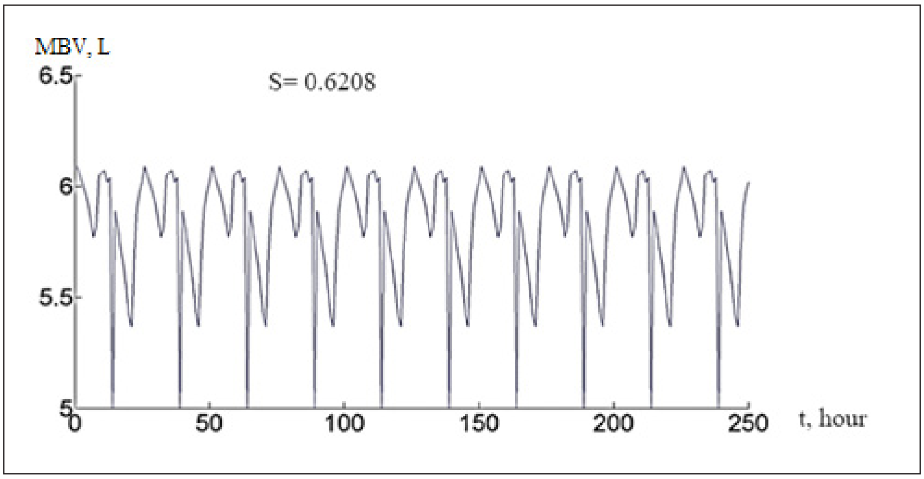


**Figure 3** – MVB daily dynamics in students before exercise stress

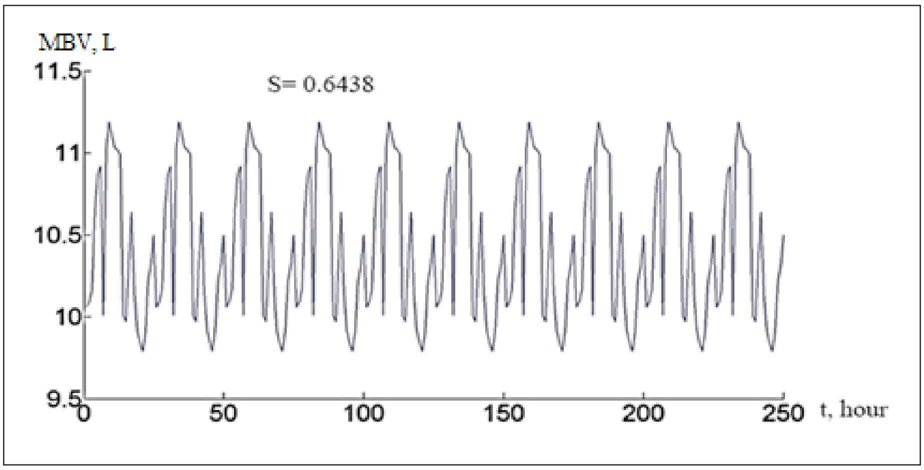


**Figure 4** – MVB daily dynamics in students after exercise stress

## Conclusion

Entropy is a well-defined quantity in physics, however its definition is fairly simple. The statement that entropy always increases can be derived from simple arguments, but it has dramatic consequences. In particular, this phenomenon explains occurrence of pathological processes [16-18].

Thus, for the first time we calculated the values of entropic indicators of the cumulative dynamics of systolic blood volume before and after the physical activity. It is established that the entropy values are lower in the norm than after the physical exercise, which indicates the energy stress in the cardiovascular system and increase of kinetic energy.

Proceeding from the above, we can draw the following conclusion: the minute volume of blood is a very sensitive and reliable indicator characterizing the reaction of the human body to the performance of a dosed physical load. All the test subjects experienced an increase in minute volume of blood values, which indicates the adequacy of adaptive processes. Between the level of activity of the cardiovascular system and the functional state of the organism, a certain statistically significant dependence is observed. It was established that the measured physical load caused the increase in the minute volume of blood value in the objects.

Ergo, it can be concluded that during the day, systolic blood volume is a subject to a slight vibrational rhythm (approximately 3-7%); the maximum values were observed at night (at 9 pm). The physical load causes an increase in the values of systolic blood volume (in the range of 11-15%). Physical activity stimulates the activity of the cardiovascular system, what in turn increases systolic blood volume leading to the rise of entropy. Similarly, in the course of the day, the minute volume of blood also changes. Entropy values for the systolic and minute blood volume.

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